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A generating voltmeter

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With 6 figures in the text

For the measurements of high voltages one often uses a generating voltmeter since this does not load the high voltage source. Several types of generating voltmeters have been constructed. The first type by KIRKPATRICK[1] has a rotating cylinder, but now the most common consists of a sectory rotor in front of stator plates, as described by VAN ATTA and others.[2] In two papers GOHLKE and NEUBERT[3] give a summary of different constructions and they also propose a new type where the moving system is vibrating instead of rotating. In this a vibrating plate forms a variable capacity together with the high voltage terminal. By the construction of a voltmeter, however, they use another vibrating type, which in principle is more like the rotating one. An earthed grating vibrates longitudinally in front of a fixed one, and when the latter is alternately screened and not, an a. c. voltage is obtained.

For the van de Graaff-generator at the physics laboratory of Uppsala University a voltmeter of a vibrating type has been built. In its simplest form the latter consists of a plate, which vibrates with the amplitude of Δd at the distance d from the high voltage terminal (Fig. 1). The a. c. voltage drop v across resistance R is[3]

$$v = i \cdot R = \frac{dQ}{dt} \cdot R = V_0 \frac{dC}{dt} \cdot R \tag{1}$$

where V_0 is the high voltage and C the capacity between the plate and the van de Graaff-sphere. C can be expressed

$$C = C_0 + C_1 \cdot \sin \omega t \tag{2}$$

C_0 and C_1 being constants. Differentiating Eq (2) and inserting (1) gives

$$v = V_0 \omega C_1 R \cos \omega t \tag{3}$$

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[1] P. KIRKPATRICK, F. MIYAKE; Rev. Sci. Instrum. 3, 1 (1932). — P. KIRKPATRICK; Rev. Sci. Instrum. 3, 430 (1932).

[2] L. C. VAN ATTA, D. L. NORTHRUP, C. M. VAN ATTA, R. J. VAN DE GRAAFF; Phys. Rev. 49, 761 (1936).

[3] W. GOHLKE, U. NEUBERT; ZS. f. techn. Phys. 21, 217 (1940). — W. GOHLKE, U. NEUBERT; ZS. f. techn. Phys. 23, 70 (1942).

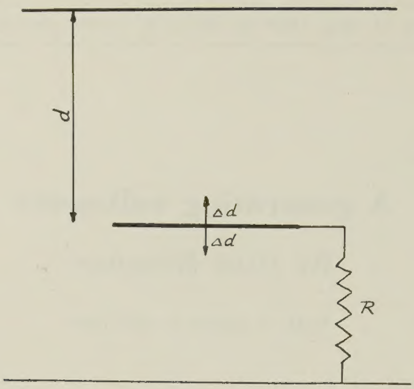

Fig. 1.

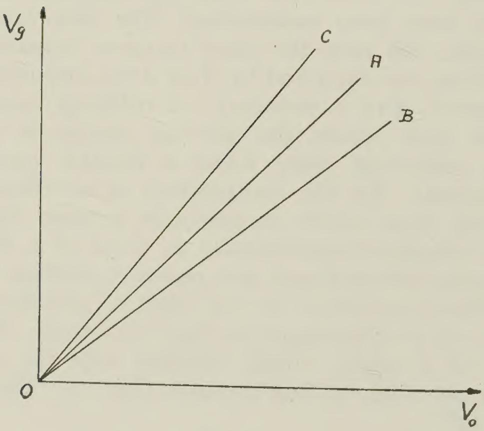

Fig. 2.

or

$$v = V_0\,\omega\,\frac{C_1}{C_0}\,R\,C_0\cos\omega t \tag{4}$$

but $\dfrac{C_1}{C_0} \approx \dfrac{\Delta d}{d}$

$$v = V_0\,\omega\,\frac{\Delta d}{d}\,R\,C_0\cos\omega t \tag{5}$$

Across resistance R we get the effective a. c. voltage

$$v_{\text{eff}} = \frac{V_0}{\sqrt{2}}\,\omega\,\frac{\Delta d}{d}\,R\,C_0 \tag{6}$$

of frequency $n = \dfrac{\omega}{2\pi}$.

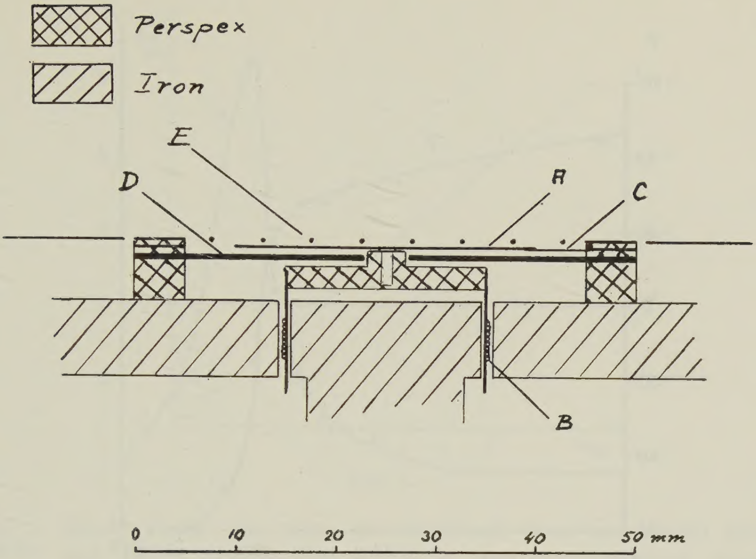

Fig. 3.

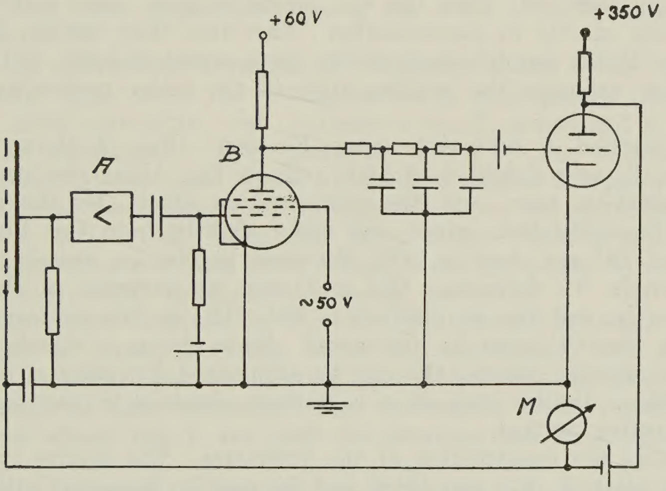

Fig. 4.

Proportional to V_0 is v, and can be used as a measure of the high voltage, provided that amplitude Δd is constant. This is however difficult to attain, and therefore it is better to use compensation. Thus a suitable d. c. voltage is applied on a grating in front of the plate. The d. c. voltage which brings the plate signal to zero is directly proportional to the high voltage.

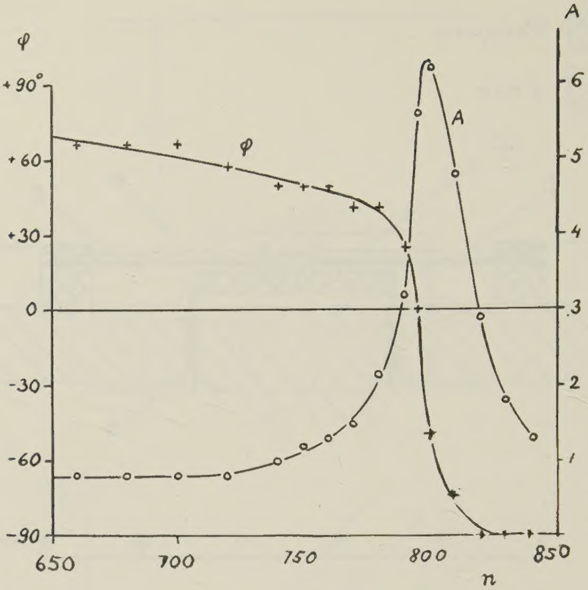

Fig. 5.

The instrument can be made direct-reading if the rectified plate voltage is used for compensation.[1] Then the a. c. signal is never zero, and the voltmeter does not work exactly in compensation. The error thus arising, however, will be made less if the amplification of the plate signal is high, and can be made less than for example the reading error of the meter measuring the grating voltage.

By this method a difficulty arises, however. Fig. 2 shows the grating d. c. voltage V_g as a function of high voltage V_0. Along the straight line OA the a. c. signal is zero, and the compensation exact. By the direct-reading voltmeter the calibration curve will differ slightly from this line; two other lines OB and OC are possible. OC, however, implies an unstable equilibrium. If, for example, V_0 decreases, this will give an increase in the a. c. signal and thus in V_g, and the equilibrium is lost. OB, on the contrary, is a stable state. Thus, line OC must be eliminated. Since the a. c. signals on both sides of OA have opposite phases, OC can be eliminated by using a phase-sensitive rectifying stage. In this way an a. c. voltage obtained in the field above OA causes no grating voltage.

Fig. 3 shows the construction of the voltmeter. The moving system consists of vibrating plate A (0.2 mm thick and 30 mm in diameter) with an ordinary loudspeaker coil B. The plate is supported by three piano wires C. Between the plate and the coil there is an earthed shield D. The grating E consists of 0.5 mm wires spaced 5 mm apart.

The coil is fed by an RC-oscillator of a frequency of 600–900 cycles; the amplitude of the plate being about 0.1 mm.

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[1] A similar construction is described by G. P. Harnwell, S. N. Van Voorhis; Rev. Sci. Instrum. 4, 540 (1933).

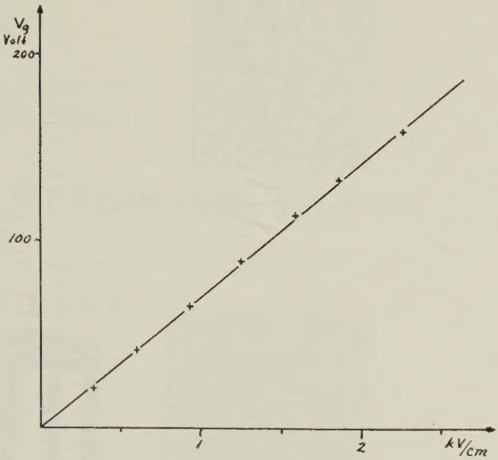

Fig. 6.

The a. c. signal from the plate is amplified in a two-staged amplifier A (with CF50 and DF21 tubes) Fig. 4. B is the phase-sensitive stage, which rectifies the a. c. signal if it has the right phase. The screen grid is fed by 50 volt a. c. from the oscillator, and the grid bias is adjusted so that the tube is conducting only when an a. c. signal of the same phase as that of the oscillator appears. The rectified voltage is then filtered and is amplified in a triode 6C5. The total amplification is of the order 10^6. The grating voltage is read on meter M.

The vibrating system has a resonance frequency of 800 cycles, and the a. c. signal from the plate when the voltmeter fed by a frequency near resonance is of rather good sine-form, but contains a small component of the second harmonic. The resonance is very sharp, as shown by Fig. 5, where the amplitude and phase of the plate signal are plotted against frequency. The phase is very unstable at resonance, so it is better to drive the voltmeter at a lower frequency, e. g. 700 cycles. Then the error of the phase is 60°, but in the amplifier is inserted a low pass filter which turns the phase 60° and also cuts away higher frequencies, especially the second harmonic.

A calibration curve is given in Fig. 6. This calibration, which shows that the instrument is linear, is made at a low electrostatic field strength. In stronger fields one must put the grating nearer the plate, or place an earthed grating in front of the voltmeter. The instrument works rapidly, the time constant being about 0.5–1 sec, and the accuracy will be of the order of 1 per cent.

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